Time Resolved GRB Spectroscopy[1]

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Abstract. We present the main results of a study of time-resolved spectra of 43 intense GRBs detected by BATSE. We considered the 4-parameter Band model and the Optically Thin Synchrotron Shock model (OTSSM). We find that the large majority of time-resolved spectra of GRBs are in remarkable agreement with the OTSSM. However, about 15 % of *initial GRB pulses* show an apparent low-energy photon suppression. This phenomenon indicates that complex radiative conditions modifying optically thin emission may occur during the initial phases of some GRBs.

INTRODUCTION

We study a sample of 43 GRBs selected for the high-quality of their time-resolved spectra obtained with the BATSE Spectroscopy Detectors (sensitive in the energy range $25 - 1800$ keV). The time over which each spectrum was accumulated was varied so that the signal-to-noise ratio was greater than 15 (in the hard X-ray energy band). These data provide excellent temporal resolution: in many cases we obtain more than 10 spectra per burst with accumulation times as short as 256 ms.

SPECTRAL MODELS

We fitted each GRB time-resolved spectrum with two models: (1) the Band model [1], and (2) the Optically Thin Synchrotron Shock Model (OTSSM) [3,4]. The (purely phenomenological) 4-parameter Band model [1] consists of two power-law components (of spectral indexes α and β) joined smoothly by an exponential roll-over near a break energy E_0.

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$$N(E) = A\left(\frac{E}{100\,\mathrm{keV}}\right)^{\alpha} \exp\left(-\frac{E}{E_0}\right) \qquad \text{for } E \leq (\alpha-\beta)\,E_0 \quad (1)$$

$$N(E) = \left[A\left(\frac{(\alpha-\beta)\,E_0}{100\,\mathrm{keV}}\right)^{\alpha-\beta} \exp\left(\beta-\alpha\right)\right]\left(\frac{E}{100\,\mathrm{keV}}\right)^{\beta} \qquad \text{for } E \geq (\alpha-\beta)\,E_0 \quad (2)$$

We used the (three-parameter) OTSSM of Refs. [3,4]. We performed an independent spectral fitting for the Band and OTSSM models for each of the time-resolved spectra of all GRBs of our sample. For each GRB we obtain 4 (3) best fit parameters as a function of time representing the complete spectral evolution.

RESULTS

We find GRB spectral evolutions of two types: (1) a "tracking behaviour", with spectral parameters in approximate one-to-one correspondence with the changing energy flux, and (2) a "hard-to-soft evolution", with spectral parameters evolving independently of the energy flux (see, e.g., ref. [2]).

Fig.1 shows the distribution for *all* collected time-resolved spectra of the low-energy spectral index α. A few bursts show values $\alpha \geq -2/3$ typically during the initial-rising part of their most intense pulses. The high energy spectral index β is less constrained, and in some cases varies substantially over consecutive spectra within the same burst. The β distribution (Fig.2 – left panel) is peaked near –2 for the Band model representation, and is broader for the OTSSM fits. Break energies E_0 are typically well below 500 keV. Interestingly, we find that the OTSSM provides a very good representation of time-resolved spectral data. Fig.2 (right panel) show the cumulative distribution of the reduced χ^2 for the Band and OTSSM models.

DISCUSSION

We studied 43 GRBs from the BATSE spectral archive selected by their large signal-to-noise ratios. We collected information for a total of 1046 spectra.

Our results indicate that the OTSSM is quite successful in describing the majority of GRB spectra. Fig.3 shows the spectral evolution of the remarkable GRB 990123 demonstrating the validity of the OTSSM for very intense bursts. However, violations of the simple OTSSM are apparent in about 15% (at 3σ level) of our time resolved spectra. These violations (typically with a low-energy index $\alpha > -2/3$) always occur at the beginning of major GRB pulses (as in Fig.4).

The OTSSM was derived [3] for idealized plasma and hydrodynamic conditions that are most likely valid far from the central source. Several plasma and dynamic conditions (probably involving emission sites close to a central object) may produce the apparent suppression of soft photons at the beginning of some GRB pulses.

REFERENCES

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4. Tavani, M., Ghirlanda G., Band D.; in preparation (2000).

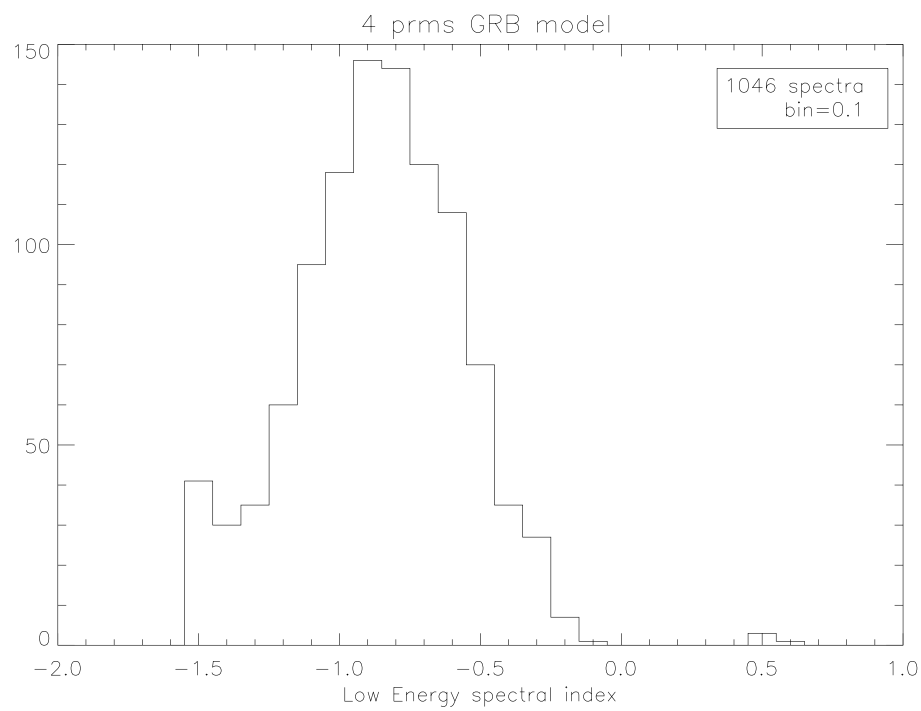

FIGURE 1. Low-energy (α) spectral index distribution from all the time-resolved spectra

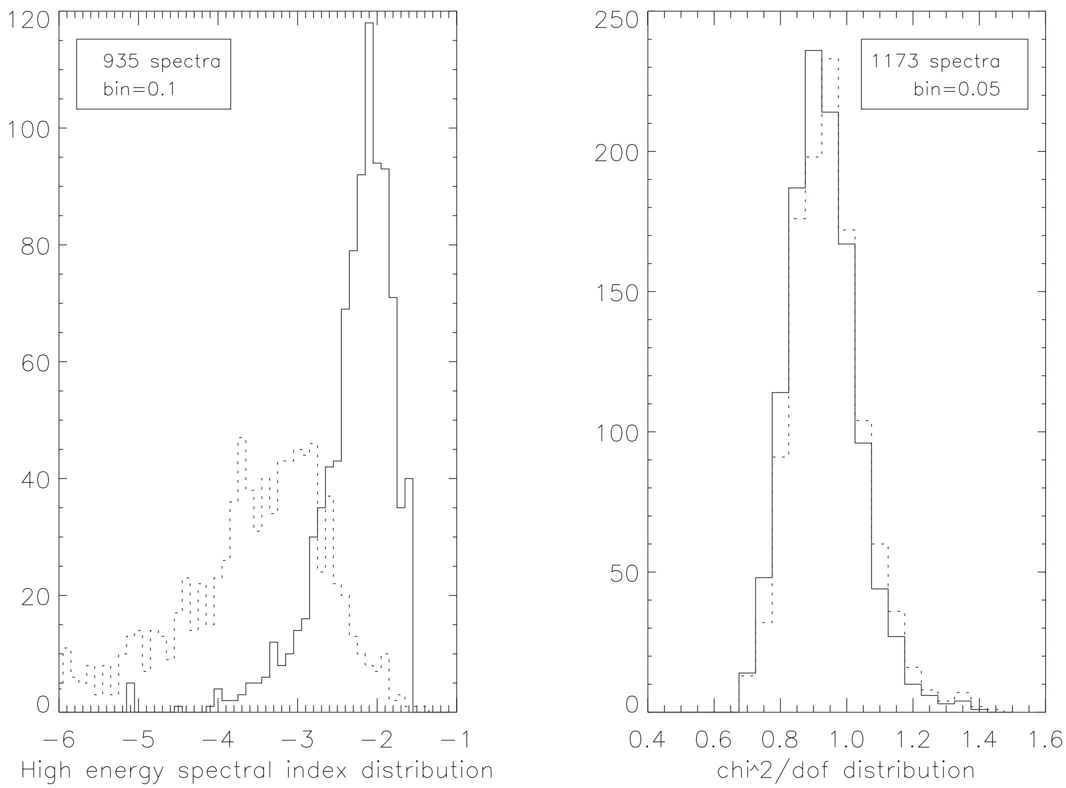

FIGURE 2. *Left panel:* High energy spectral index β distributions for the Band model (*solid line*) and the OTSSM (*dotted line*). *Right panel:* Reduced χ^2 distributions.

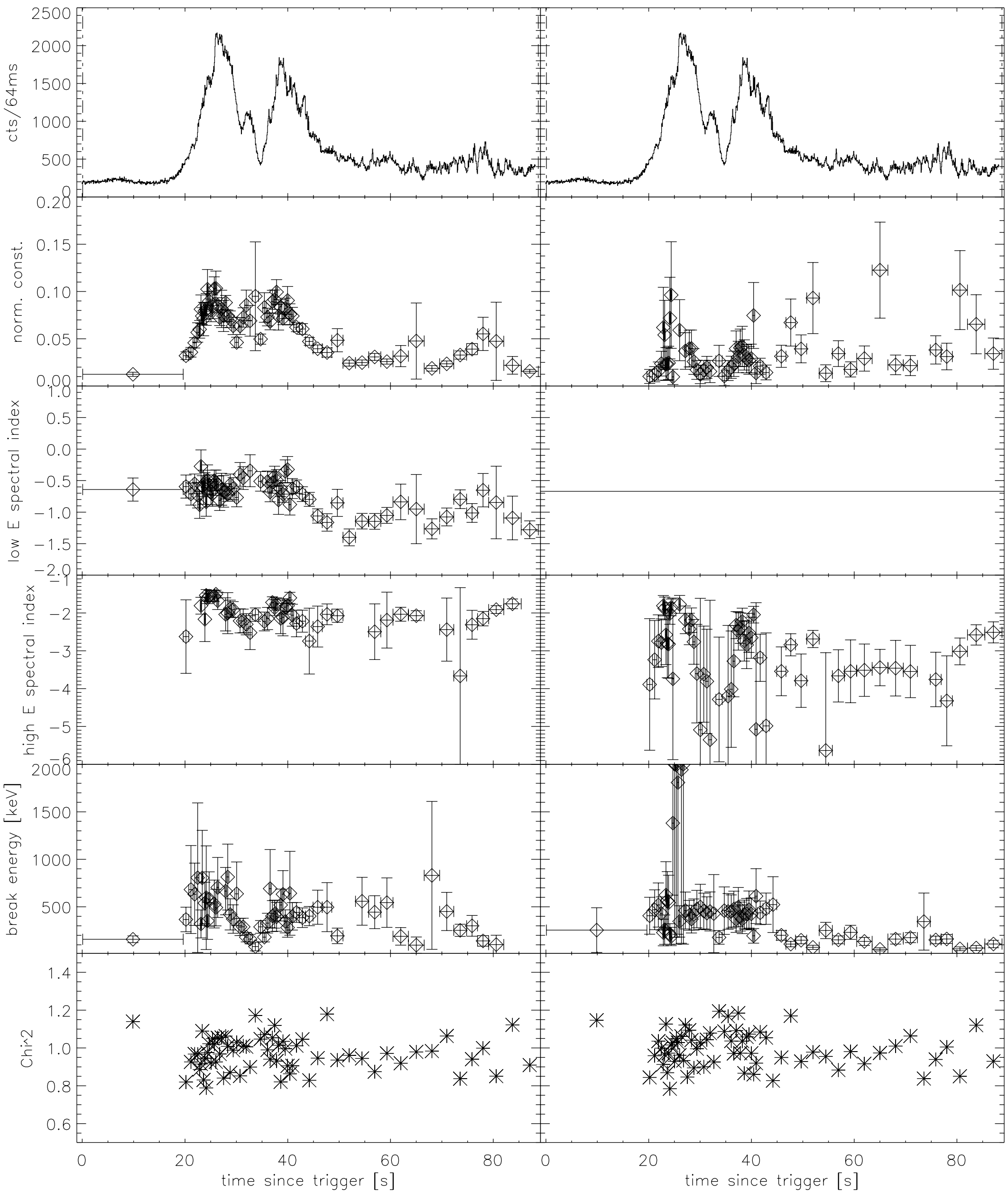

FIGURE 3. GRB 990123 spectral evolution of the 4-parameter Band model (*left column*) and the 3-parameter OTSSM (*right column*). The α parameter is fixed in the OTSSM.

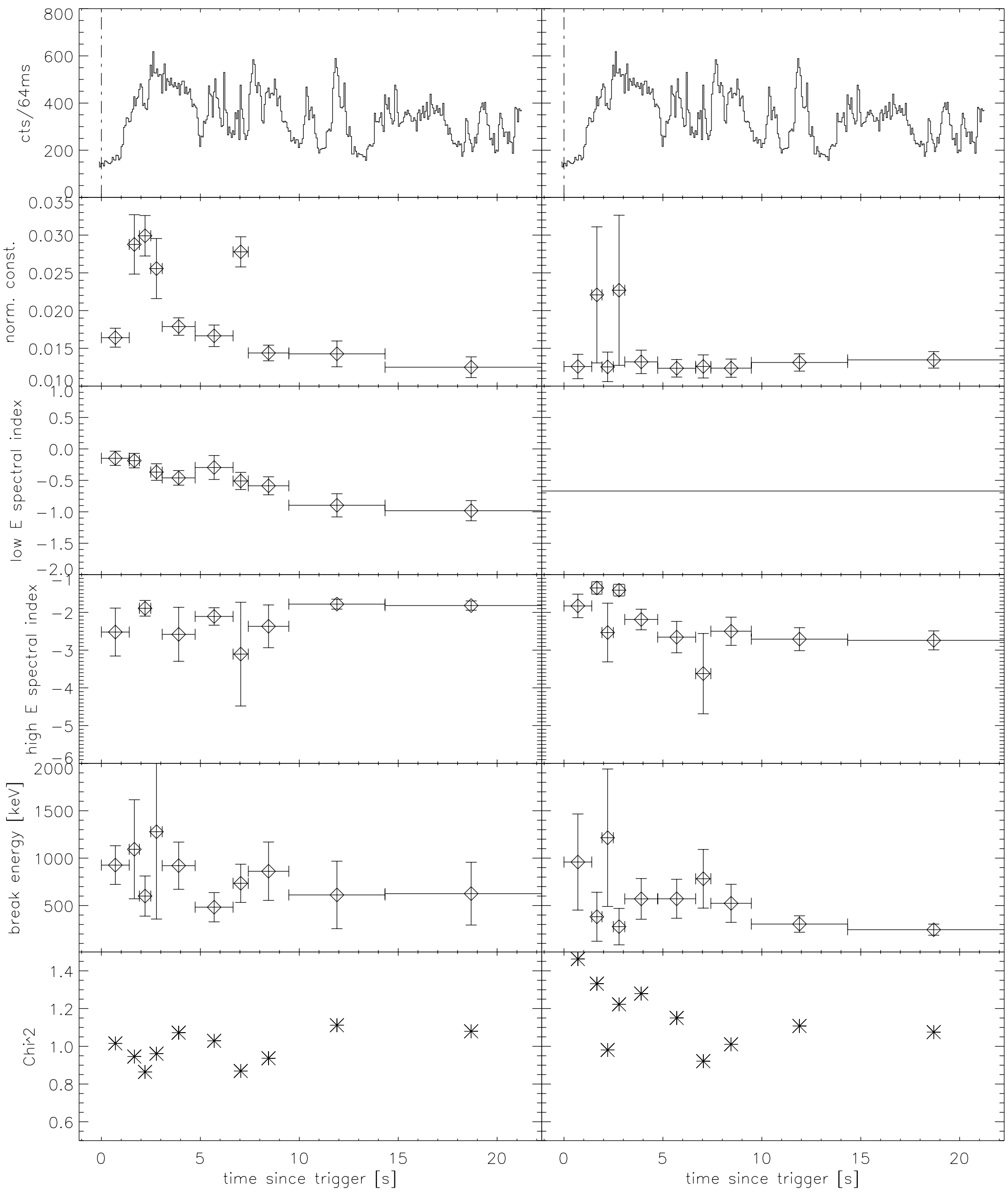

FIGURE 4. GRB 910814 spectral evolution of the 4-parameter Band model (*left column*) and the 3-parameter OTSSM (*right column*). The α parameter is fixed in the OTSSM.